Earth Albedo Measurements: July 1963 to June 1964

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The geographic distribution of incoming solar radiation has been determined from an analysis of the TIROS VII visible channel data for the period 1 July 1963 to 30 June 1964. The raw data, described in the *TIROS VII Radiation Data Catalog* (Staff Members, 1964), consist of measurements of the intensity of solar radiation scattered from the earth-atmosphere system as received by a 5-channel "medium resolution" scanning radiometer at an altitude ranging from 620 to 650 km. The field of view of the radiometer is approximately a cone with half-angle 3°. The effective spectral response of the radiometer channel used in this analysis is from

0.55 to 0.75 μ. The geographic region covered by the measurements, called the "quasi-globe," encompasses approximately 85% of the earth's surface; excluded are the polar regions beyond 60° latitude in each hemisphere and two small areas, one around the southern tip of South America and the other over Siberia, amounting to 1% of the earth's surface.

This study differs from previously reported work (Bandeen *et al.* 1965; Rasool and Prabhakara, 1966; Winston, 1967) in that the dependence of the measured intensity on the solar zenith angle ξ, the satellite zenith angle θ, and the relative azimuth angle between sun and satellite ψ is taken into account in reducing the measurements. The method used is the same as that applied to the TIROS IV radiation data previously reported[1] and is summarized as follows.

The intensity measurements are first analyzed to obtain the angular distribution of the intensity of reflected solar radiation averaged over the quasi-globe, $\bar{I}\ (\theta,\psi,\xi)$. Integration over the solid angle provides the corresponding mean quasi-global flux,

$$\bar{F}(\xi)=\int_0^{2\pi}\int_0^{\pi/2}\bar{I}(\theta,\psi,\xi)\cos\theta\,\sin\theta d\theta d\psi.$$

The ratio $\bar{F}(\xi)/\bar{I}(\theta,\psi,\xi)$ constitutes a table of correction factors for converting intensity measurements into flux.

Each measurement of intensity is in this way converted to a measurement of flux, and its ratio to the incident solar flux provides the *reflectance* at that particular time and at that solar zenith angle. At any geographic location the reflectance changes throughout the day not only because of changing atmospheric conditions but also because of a changing solar zenith angle. For example, with constant meteorological and surface conditions, the reflectance would change by a factor of 1.5 between noon (when the sun in near the zenith) and later in the afternoon when the sun is 30° above the horizon (Arking, *loc. cit.*). This effect, which is neglected in the earlier analyses of satellite radiation measurements, makes it necessary to distinguish between *reflectance* and *albedo*. The term *albedo* is here defined as the ratio of *reflected solar flux* to *incident solar flux* at a given geographic location for the time interval specified. In the present study, the albedo is derived from the satellite samples of reflectance by averaging the time-dependent reflectance from sunrise to sunset, *weighted by the amount of incident solar energy.*

If we let I be a single intensity measurement at time t and at angles θ,ψ and ξ, the reflectance is given by

$$R=\frac{I}{F_0\cos\xi}\cdot\frac{\bar{F}(\xi)}{\bar{I}(\theta,\psi,\xi)},$$

[1] Arking, A., 1964: The angular distribution of scattered solar radiation and the earth albedo as observed from TIROS. Presented at the Symposium on Atmospheric Radiation, International Association of Meteorology and Atmospheric Physics (IUGG), Leningrad, USSR, August 1964.

and the albedo derived from the measurement is given by

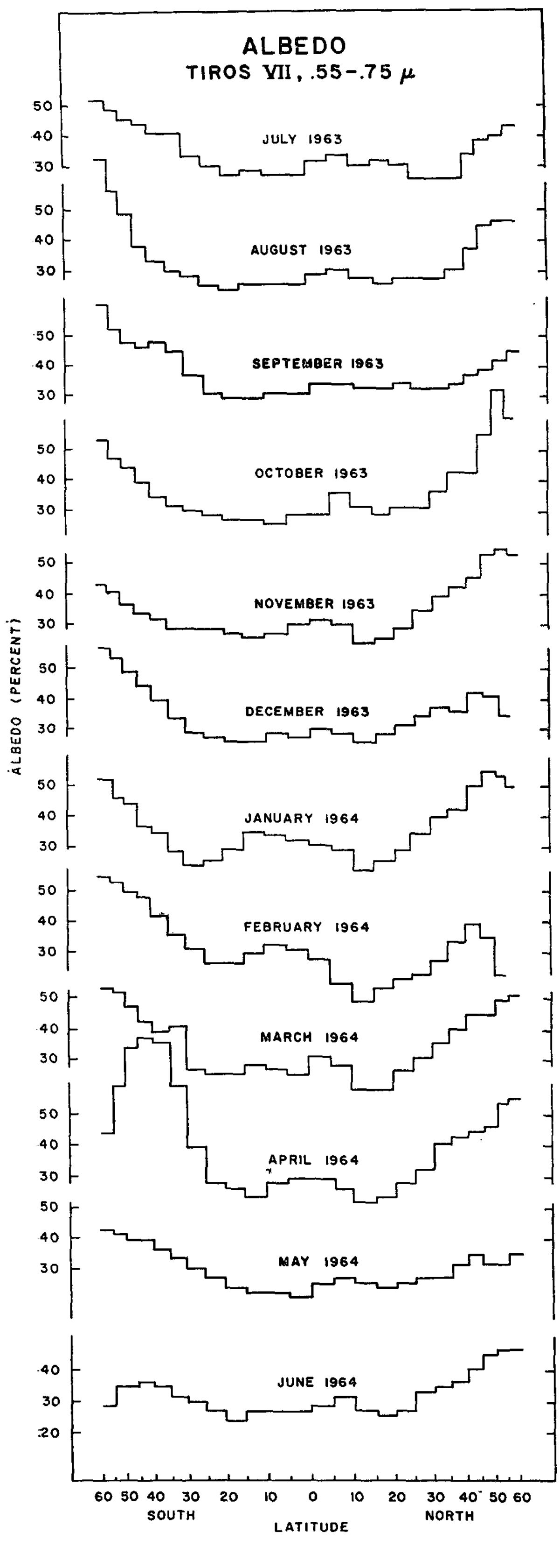
$$A=\frac{I}{\bar{I}(\theta,\psi,\xi)}\cdot\frac{\int_{t_1}^{t_2}\bar{F}(\xi(t))\cos\xi(t)dt}{\int_{t_1}^{t_2}F_0\cos\xi(t)dt},$$

where F_0 is the solar flux normal to the incoming beam (taken to be 2 cal cm^{-2} min^{-1} or 1395 W m^{-2}) and t_1 and t_2 are the times of sunrise and sunset, respectively. The functional relationship between solar zenith angle and time $\xi(t)$ varies with season and latitude in a readily computable manner.

One other correction to the raw measurements was required. The readings are marred by a very noticeable degradation in the response of the radiometer after launch (Staff Members, 1964). This has been observed, as well, on previous flights of these radiometers and the cause is not fully understood, although possible explanations have been offered (Bandeen *et al.*, 1963). Correction factors for the degradation were determined by analyzing the intensity of scattered solar radiation over the Sahara desert and observing its change throughout the 1-yr period. The Sahara was chosen because it has a minimum of cloud cover and most of the scattered radiation is due to reflection from the surface (which is assumed to have little variation over the year). To avoid the problems associated with the angular dependence of the scattered radiation, measurements were restricted to a narrow range of angles over which the reflectance is nearly constant. In each of six 4°×4° latitude-longitude intervals within the Sahara region, the radiometer readings showed variations which generally decreased with time. From the plot of radiometer readings vs. time, a multiplicative correction factor, proportional to time, was determined which eliminated the general decrease. (In effect a straight line through the plotted points, fitted by least squares, was brought parallel to the time axis.) The correction factor so determined was applied to *all* radiometer readings; it is 1 for the first orbit and increases linearly to 1.336 after one year (orbit 5406). This factor turned out to be almost identical to that determined by Staff Members (1964) in a basically similar approach.

With these corrections for instrumental degradation, the albedo, averaged over the quasi-global region and over the year, is 20.6%. If one were to include the polar regions, with values of the albedo assumed to range between 50 and 75%, the resulting *global* albedo would range between 23 and 25%, appreciably lower than the values determined in climatological studies, ~35% (Fritz, 1949; Houghton, 1954; London, 1957).

The possibility has been raised by Bandeen *et al.* (1965) that the visible channel radiometer may have degraded during launch operations. They based their suspicion on a higher value of albedo implied by the



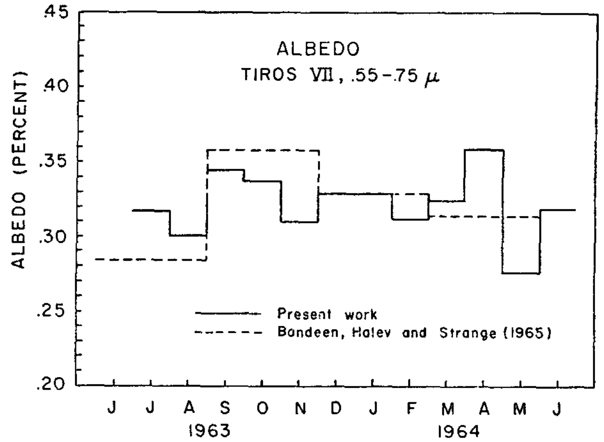


FIG. 2. The seasonal variation of albedo as determined from the TIROS VII 0.55–0.75 μ data. Monthly values from the present study are indicated by the solid line for the period July 1963 to June 1964. Three-month averages from Bandeen *et al.* (1965) are indicated by the dashed line for the period June 1963 to May 1964. The ordinate scale for each curve was multiplied by different scale factors to adjust the mean quasi-global albedo to 32.2%. See text for explanation.

infrared data. Using the 8–12 μ channel of the TIROS VII radiometer (with its own degradation problem), they determined a mean albedo over the solar spectrum, for the year, and for the region covered by TIROS VII, of 32.2% under the assumption that the net radiation energy balance (difference between incoming solar radiation and outgoing terrestrial radiation) is zero. Further assuming that the albedo for the portion of the spectrum between 0.55 and 0.75 μ should be the same as for the entire spectrum, they found that they needed a multiplicative factor of 1.60 to raise the mean value of the albedo, as determined by *their* analysis of the visible channel data, to 32.2%

Although such assumptions are highly questionable, for comparison purposes we also scaled our results to make the mean value of the albedo 32.2% for the year. The multiplicative factor required in our case is slightly less, 1.56. The extremely small difference between their correction factor and ours indicates that global averages over the entire year include a sufficiently random sampling of the relevant solar and satellite angles.

With the corrections and scale factor described above, the monthly mean latitudinal distribution of albedo is shown in Fig. 1 for the period July 1963 to June 1964. The curve for each month shows maxima at the higher latitudes of each hemisphere and a smaller peak near the equator. This is characteristic of cloud cover patterns (London, 1957; Arking, 1964). The position of the equatorial peak is observed to follow, more or less, the solar declination with perhaps a lag of about a month.

FIG. 1. The latitudinal distribution of albedo as determined from the TIROS VII 0.55–0.75 μ data for 12 months beginning with July 1963. The ordinate was multiplied by a scale factor to adjust the mean quasi-global albedo for the year to 32.2%. See text for explanation.

The albedo for that portion of the globe covered by the TIROS VII satellite (with small exceptions, the region between $-60°$ and $+60°$ latitude) is shown in Fig. 2. Our results (solid histogram) are plotted monthly from July 1963 to June 1964. The results of Bandeen *et al.* (1965) (dashed histogram) are plotted as 3-month averages starting with June-July-August 1963 through March-April-May 1964. There is excellent agreement for the period December 1963 to May 1964 but a very marked discrepancy for the period September to November 1963, which we can attribute only to our consideration of the angular dependence of the scattered radiation.

With one exception (transition from April to May) the month-to-month variations of albedo are significantly smaller than indicated by the lunar earthshine studies of Danjon (1936) but are consistent with the relatively small variations found in a climatological study by London (1957).

A more detailed presentation of the analysis and results is given by Levine (1967), a published version of which is in preparation.

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